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RESEARCH MEMORANDUM

EXPERIMENTAL INVESTIGATION AT SUPERSONIC SPEEDS OF TWIN-SCOOP DUCT INLETS OF EQUAL AREA. I.– AN INLET ENCLOSING 61.5 PERCENT OF THE MAXIMUM CIRCUMFERENCE OF THE FOREBODY

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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EXPERIMENTAL INVESTIGATION AT SUPERSONIC SPEEDS OF TWIN-SCOOP DUCT INLETS OF EQUAL AREA. I.- AN INLET ENCLOSING 61.5 PERCENT OF THE MAXIMUM CIRCUMFERENCE OF THE FOREBODY

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SUMMARY

Tests at Mach numbers between 1.36 and 2.01 of a twin-scoop air intake enclosing 61.5 percent of the maximum circumference of a body of revolution and located five forebody diameters behind the apex showed that the total pressure recovered after diffusion was about 10 percent greater than that attained in previous tests with an annular entrance of the same area. The recovery with both twin-scoop and annular intakes was improved when the inlet Mach number was reduced by an oblique shock wave occurring upstream of the entrance. However, the improvement that could be attained by increasing the intensity of the shock wave was limited by the presence of the boundary layer. With the twin-scoop entrance, the maximum recovery was attained with the oblique shock wave caused by a 5° deflection of the stream. This recovery was about four-fifths of that of a normal shock wave occurring at the same Mach number at which the model was tested.

INTRODUCTION

The total pressure recovered after diffusion with the annular duct entrances of reference 1 was found to be roughly two-thirds of that through a normal shock wave occurring at the same Mach number. The cause of this relatively low recovery of pressure is the interaction between the compression in the diffusor and the boundary layer of the air flowing through the entrance. This interaction causes the boundary layer to separate when the pressure recovery has reached only a moderate value; consequently, the maximum total pressure attainable is limited.

Since two factors, the boundary layer and the pressure gradients imposed upon the boundary layer by the compression in the diffusor, are responsible for the large losses associated with this type of intake, an improvement in the pressure recovery should be possible if the two factors are diminished. The amount of boundary-layer air relative to the amount of unretarded air that enters a duct can be reduced by decreasing the circumferential length that the inlet encloses while the entrance area remains the same. The pressure gradient that is imposed upon the boundary layer when the stream is decelerated from supersonic to subsonic velocities inside the duct can be reduced if the Mach number at which the compression occurs is decreased. This reduction can be accomplished by decelerating the stream through one or more oblique shock waves upstream of the entrance.

It is the purpose of the present report to describe tests upon an inlet designed according to the foregoing considerations to provide a greater recovery of total pressure than is attainable with an annular entrance that is situated in a region of appreciable boundary layer.

SYMBOLS

H total pressure

M Mach number

A area

m rate of mass flow

The subscripts indicate the station of the measured quantity.

o free stream

1 duct entrance

s settling chamber

4 exit throat

APPARATUS AND TESTS

The tests were performed in the Ames 8- by 8-inch supersonic wind tunnel at Mach numbers between 1.36 and 2.01 and Reynolds numbers, based upon the length of body ahead of the entrance, between 2.23 and 3.09 million. The equipment and methods used during the investigation are described in reference 1.

The model is shown in figure 1, and the dimensions are given in figure 2. The forebody is the same as that of model B of reference 1; it consists of a 10-caliber ogival nose followed by a cylindrical section. The length of the body ahead of the scoops is five forebody diameters. The scoops are diametrically opposed and enclose 61.5 percent of the maximum circumferential length of the forebody. The intake area is the same as that of the models of reference 1, or about one-third of the projected frontal area of the station at the entrance. The subsequent duct consists of a subsonic diffusor that diverges at an equivalent cone angle of 12.6° with an area ratio of 4.8 between the inlets and the settling chamber. The exit of the passage through the model is a throat of variable area to permit control of the pressure in the settling chamber. For all of the conditions of the tests, the pressure ratio across this throat was sufficient to maintain sonic velocity through it.

The twin-scoop models were constructed by casting the portion ahead of the settling chamber from a thermo-setting plastic. The settling chamber and the supports were made of brass and steel, respectively.

In order to decrease the Mach number at the duct entrance, a model was tested that had a ramp ahead of each intake to deflect the stream and produce an oblique shock wave. Ramps having straight sides and angles of 2.5°, 5°, 9°, and 11.3° were tested to determine the optimum deflection; a photograph of the model with a 5° ramp is shown in figure 3(a). The ramp angle was changed by decreasing the length of the ramp while the height remained the same. A model having no ramp was tested in order to show the improvement in the total-pressure recovery caused by a reduction of the inlet Mach number and also to show, by a comparison with the annular intake of reference 1, the improvement that results from a decrease in the proportion of boundary layer to free air that flows through the duct entrance. A model with an annular inlet of the same area as that of the twin-scoops and a ramp angle of 5° (fig. 3(b)) was tested in order to compare the improvement in total-pressure recovery resulting from the ramp with that attained with the twin-scoop models. Aside from the addition of the ramp, this model is comparable to model B of reference 1.

In an attempt to create a large pressure difference between the surface and the sides of the 2.5° and 5° ramps of the twin-scoop model, the sides of the ramps were curved as shown in figure 2. The purpose was to cause an expansion of the air flowing around the ramps in order to create a low-pressure area that would divert the boundary layer from flowing through the intakes.

RESULTS AND DISCUSSION

As shown in figure 4, the pressure recovered after diffusion with the duct inlets of the twin-scoop model is about 10 percent greater than that of the corresponding annular entrance. The addition of a ramp to either type of inlet produces an improvement in the maximum total-pressure ratio, H_s/H_o. The total pressure attainable with the annular entrance is improved about 6 percent and that with the twin-scoop entrance about 9 percent by the reduction in the inlet Mach number resulting from the oblique shock wave created by a 5° deflection of the flow along the forebody. This greater improvement with the twin-scoop model is possibly the result of the three-dimensional character of the flow about the scoops that permits some of the boundary layer to flow over the sides of the ramp and around the inlets.

Figure 5 shows that a ramp angle of about 5° is the optimum for the twin-scoop entrance. The recovery is roughly four-fifths of that occurring through a normal shock wave at the Mach number at which the model was tested. An optimum ramp angle exists because two factors, the boundary layer and the oblique shock wave, influence the flow but counteract each other. The oblique shock wave tends to diminish the pressure losses as its intensity increases because the Mach number at the duct inlet is reduced and the deceleration from supersonic to subsonic velocities is less severe. However, as the intensity of the oblique shock wave increases, the adverse pressure gradient resulting from the shock eventually becomes great enough to thicken the boundary layer and to cause separation with the resulting decrease in the pressure recovery.

Curving the sides of the ramp in an attempt to divert the boundary layer to flow around the inlet produces no improvement; in fact, as shown in figure 5, the recovery is a few percent less.

The variation of total-pressure ratio with mass-flow ratio is shown in figure 6 for the twin-scoop entrance with a 5°, straight-sided ramp and in figure 7 for the annular entrance with a 5° ramp. (Mass-flow ratio is defined in reference 1 as the mass of fluid entering the inlets divided by that which would flow through a tube of the same area in the free stream.) The results with the twin-scoop model show that at Mach numbers less than 1.7 the total-pressure ratio does not decrease abruptly from the maximum as it does with the annular entrance.[1] This behavior again may be the result of the three-dimensional nature of the flow about the scoops. A variation that is not abrupt is more desirable because a small change in the mass of air flowing through an inlet will not cause a large change in pressure at the intake of an engine.

The schlieren photographs of figure 8 show that the boundary layer separates upstream of the entrance of the twin scoops in the same manner that it does with the annular entrances of reference 1. At large values of the outlet-inlet area ratio, the flow through the inlet is supersonic and the mass-flow ratio is nearly constant; the flow pattern is then like that shown in figure 8 for an area ratio of 1.4. As the area ratio is reduced, the total-pressure ratio increases toward the maximum with a relatively small change in the mass-flow ratio, as shown in figure 6. When the shock losses occur near the inlet to the subsonic diffuser, at the minimum local Mach number, they are the least, and the total-pressure ratio is the maximum. A further reduction in the area ratio causes a decrease in both the total-pressure and mass-flow ratios because the boundary layer separates upstream of the inlets. The schlieren photographs of figure 8 that were taken consecutively at an area ratio of 1.1 show that this separation is intermittent. The flow through the inlets fluctuates from supersonic, with a relatively thin boundary

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[1]The experimental technique used in determining the maximum total-pressure ratios is to set the outlet-inlet area ratio at the value that produces the maximum total-pressure recovery as indicated by the manometer board. Then points are obtained on both sides of this maximum. Therefore, the variation about the peak of the curve is accurately determined.

layer, to subsonic, with a completely separated boundary layer. The reason for the fluctuation is that after the boundary layer separates, the total pressure in the diffuser is reduced, and the cause of the separation no longer exists. The stream once again enters the inlet, the pressure rises until the gradients are sufficient to cause the boundary layer to separate, and then the cycle is repeated. With the twin-scoop inlet, the fluctuation through one scoop can be out of phase with that through the other as shown by the photographs taken consecutively at an area ratio of 1.0. When the area ratio is about 0.8 or less, the flow is almost continually separated; occasionally it does recover its normal course momentarily. The mass-flow ratios at which the flow is separated intermittently, and almost continually, are indicated in figures 6 and 7.

Although the schlieren photographs show that violent fluctuations of the flow occur, the pressure measurements did not exhibit any non-uniformity in the pressure distribution in the settling chamber nor did they show that the pressure fluctuates. The pressure-measuring system, which consists of several feet of small-diameter tubing connected to a multiple-tube mercury manometer, is too heavily damped to indicate oscillations of a relatively high frequency. It is estimated that the intermittent fluctuations observed during the tests occur at a frequency of about 15 cycles per second, since the image of the separated flow appears to flicker only slightly when studied on a viewing screen.

Schlieren photographs of the flow that passes along the sides of the scoops show that when the boundary layer separates upstream of the entry, it separates around the entire body (fig. 9).

CONCLUSIONS

Tests at Mach numbers between 1.36 and 2.01 of a twin-scoop duct inlet enclosing 61.5 percent of the maximum circumference of a body of revolution have shown the following effects:

1. The pressure recovery attainable with a duct inlet situated in a region of appreciable boundary is improved if the inlet Mach number is reduced by an oblique shock wave occurring upstream of the entrance. The permissible intensity of this shock wave is limited, however, to a relatively small compression ratio by the presence of the boundary layer.

2. The oblique shock wave caused by a ramp angle of 5° was the optimum for the twin-scoop inlet of these tests.

3. The twin-scoop inlet produced a recovery of total pressure about 10 percent greater than that attainable with the corresponding annular entrance. The recovery attained with the twin-scoop model was about four-fifths of that through a normal shock wave occurring at the Mach number at which the model was tested.

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REFERENCE

1. Davis, Wallace F., Brajnikoff, George B., Goldstein, David L., and Spiegel, Joseph M.: An Experimental Investigation at Supersonic Speeds of Annular Duct Inlets Situated in a Region of Appreciable Boundary Layer. NACA CRM No. A7G15, 1947.

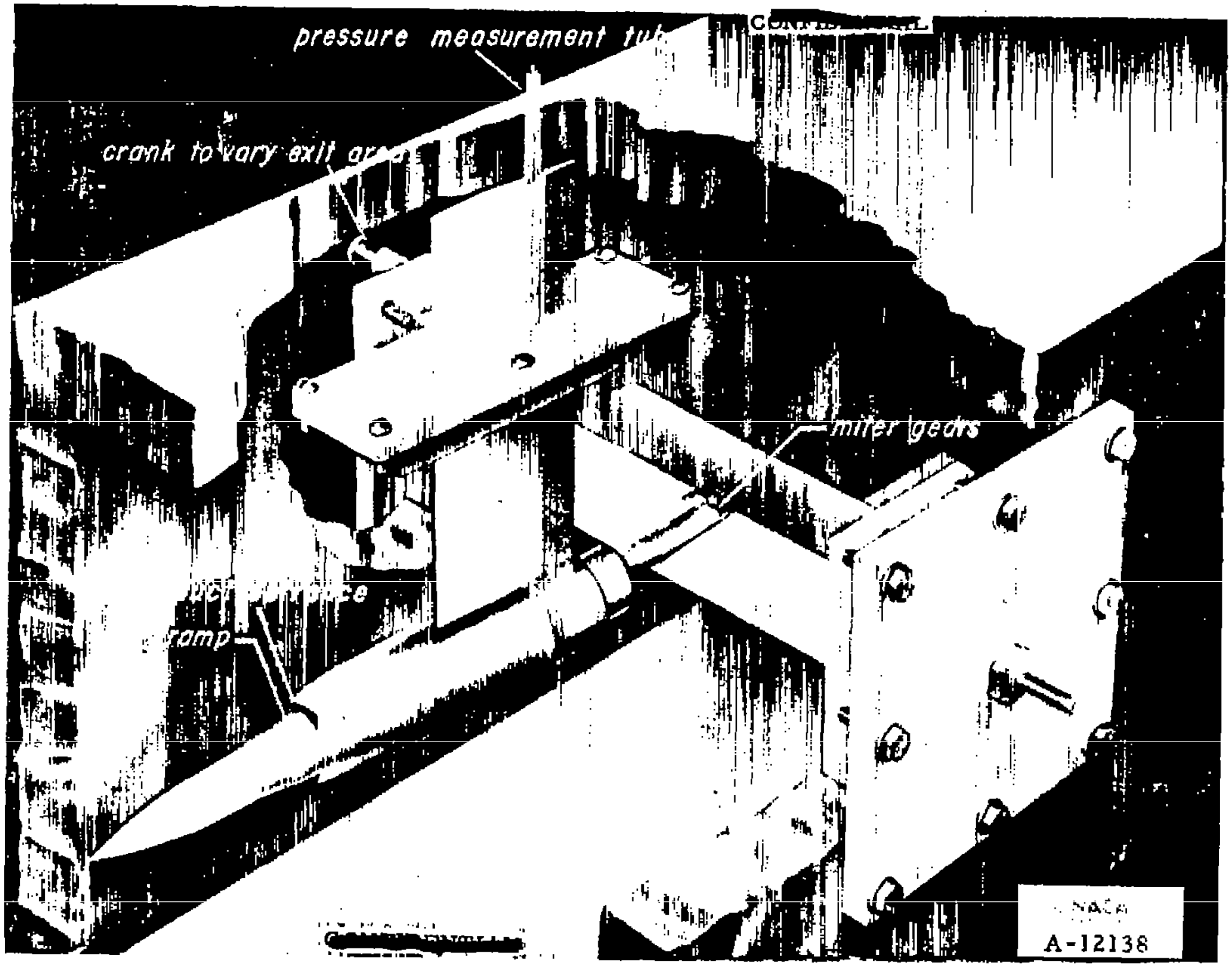

Figure 1.– Model with a twin-scoop duct inlet and a 5° ramp installed in the Ames 8– by 8–inch Supersonic Wind Tunnel.

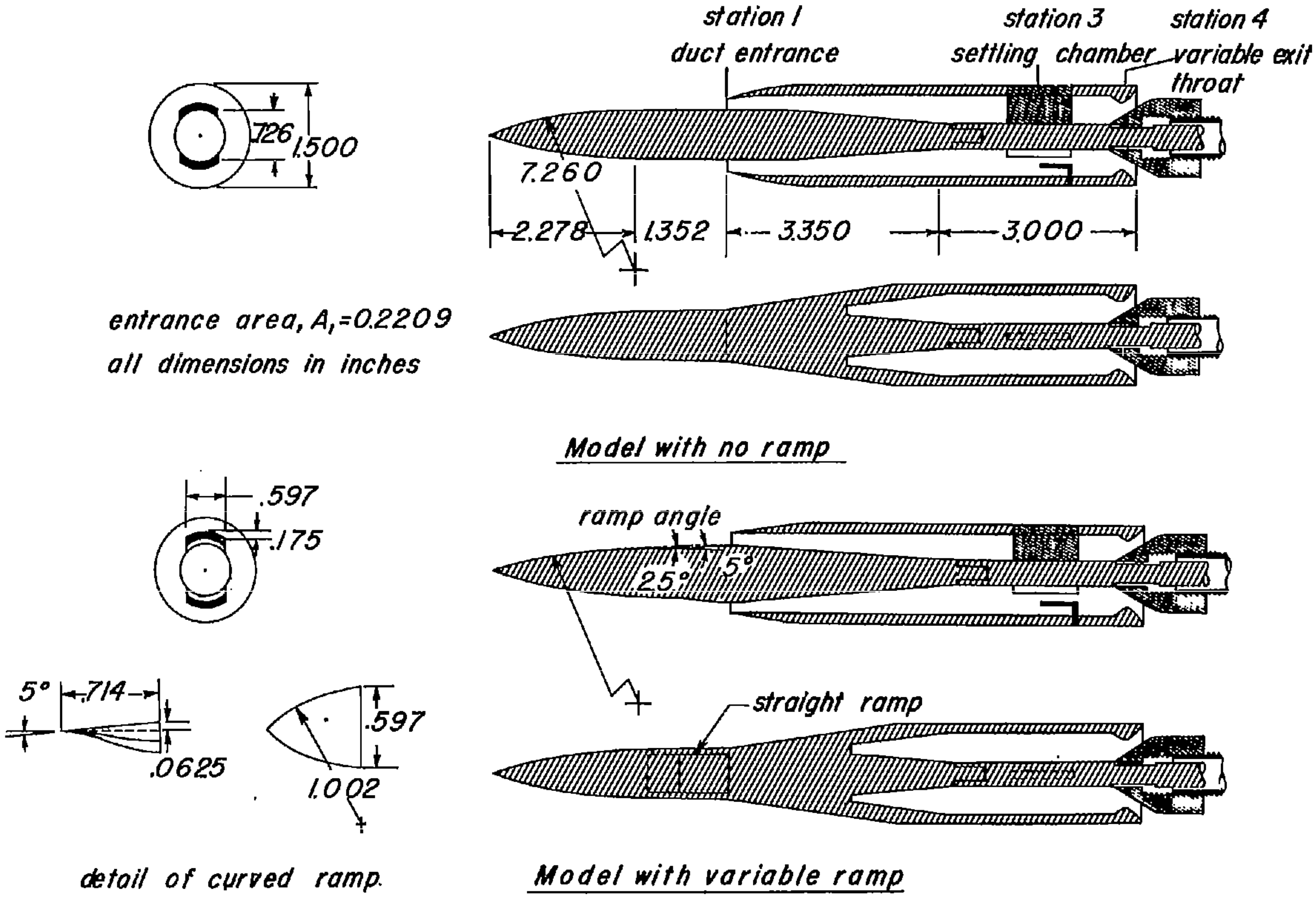

Figure 2.—Model dimensions.

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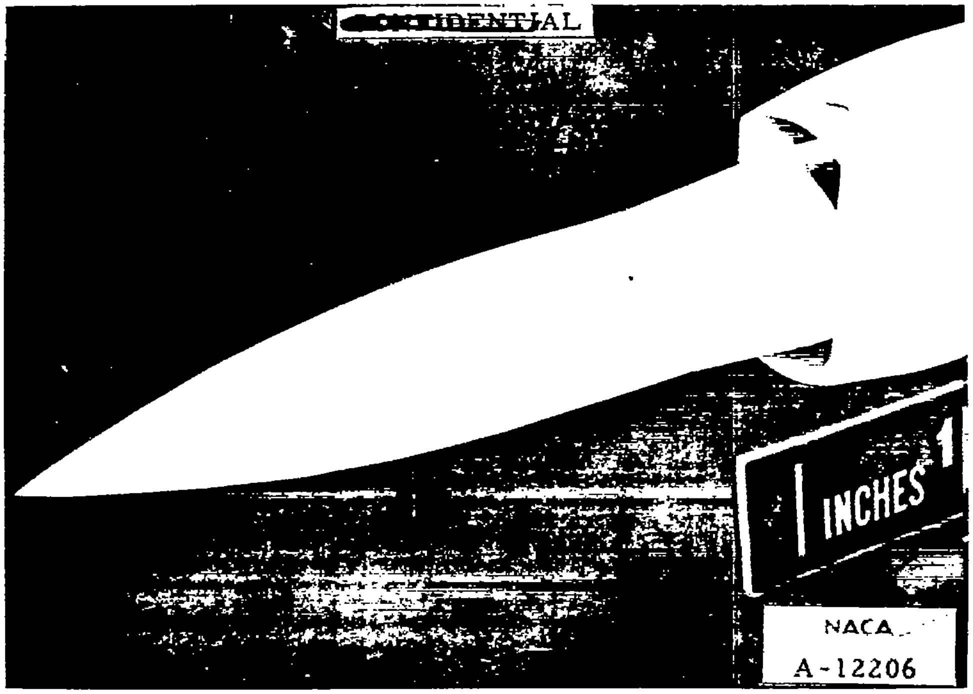
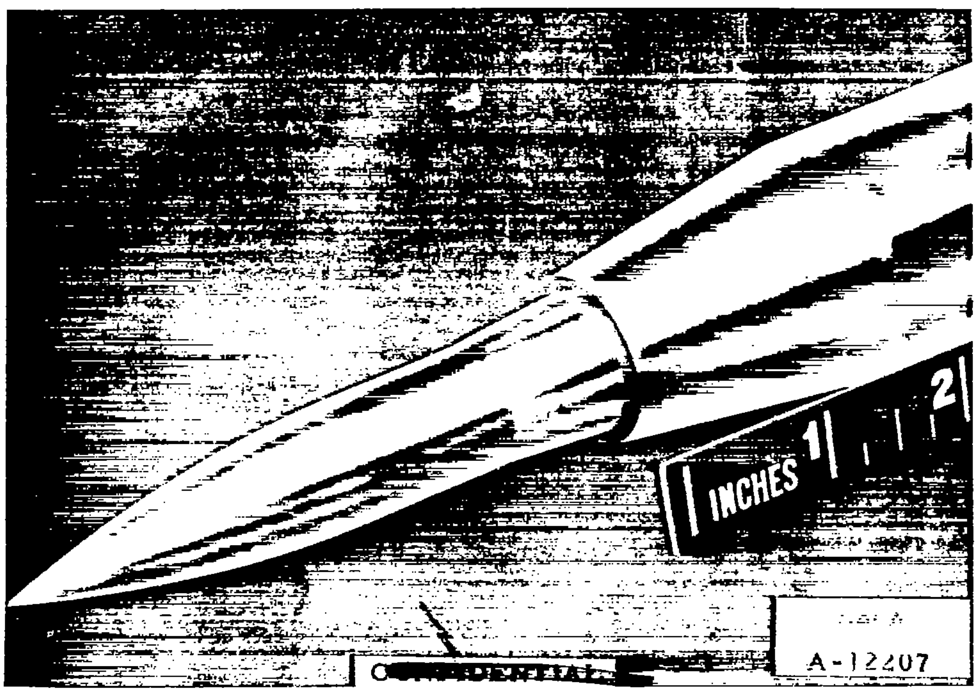


(a) Twin-scoop duct inlet.



(b) Annular duct inlet

Figure 3.– Models with a 5° ramp.

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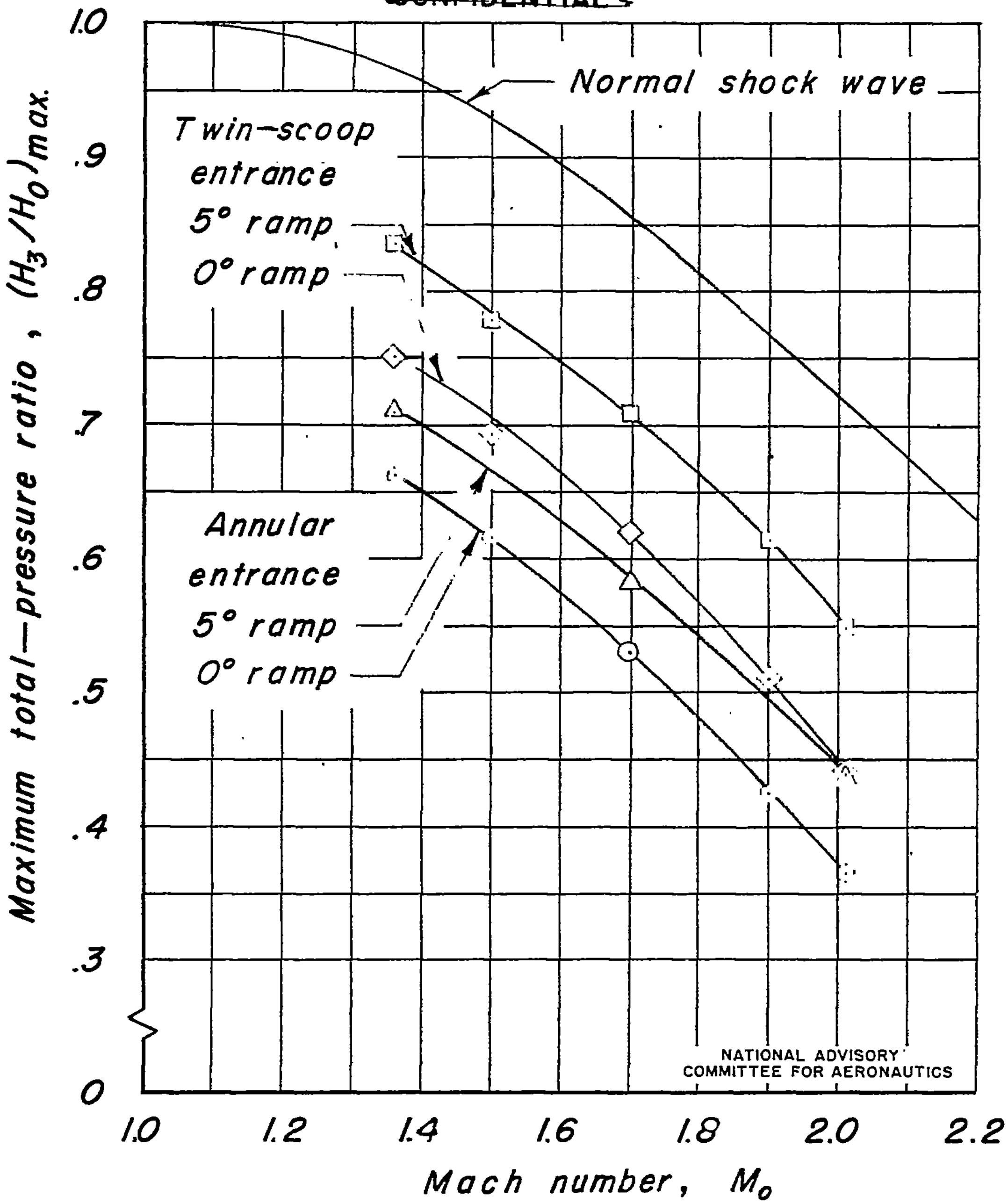

Figure 4.—Variation of maximum total-pressure ratio with Mach number.

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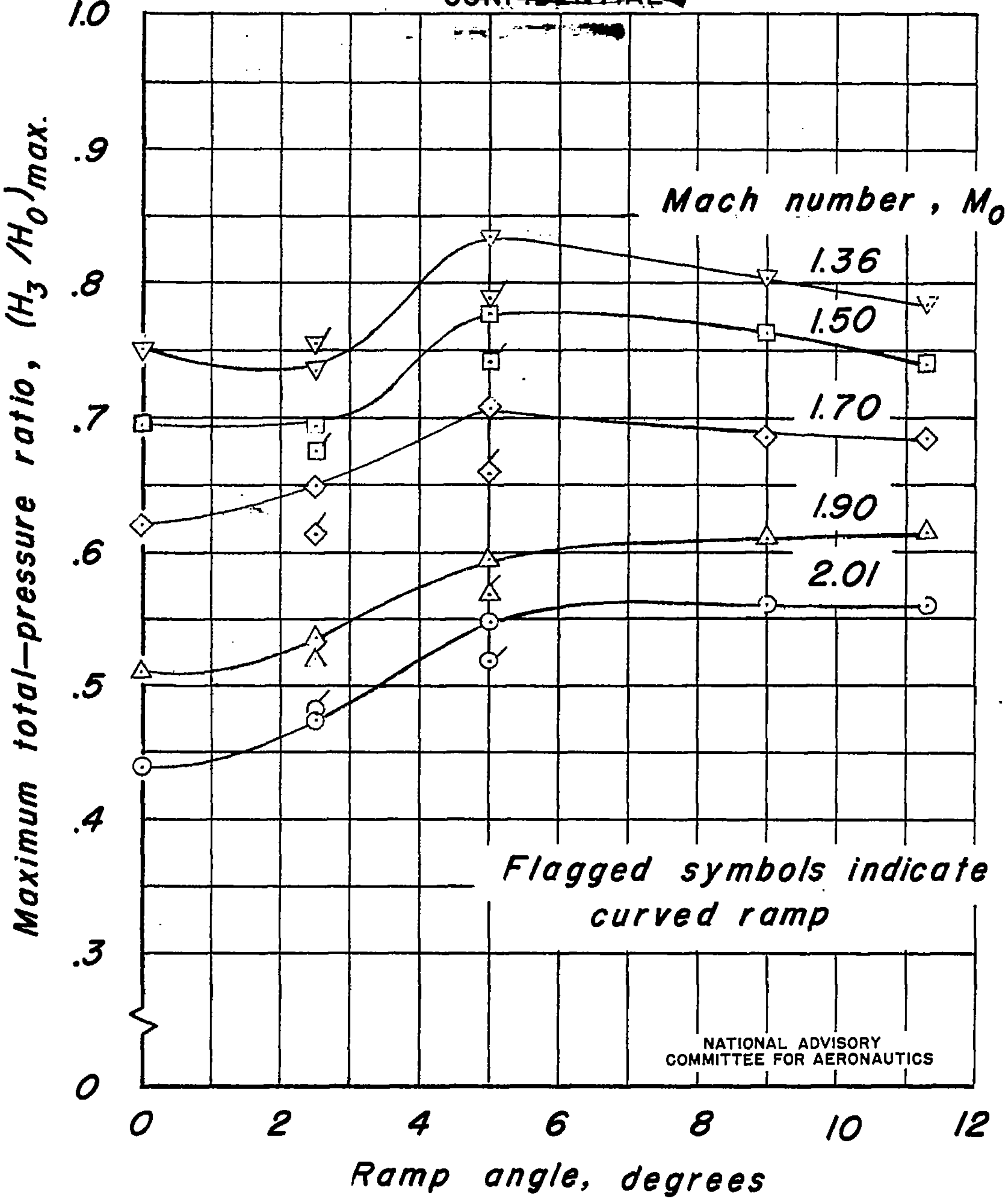

Figure 5.- Variation of maximum total-pressure ratio with ramp angle for the twin-scoop inlet.

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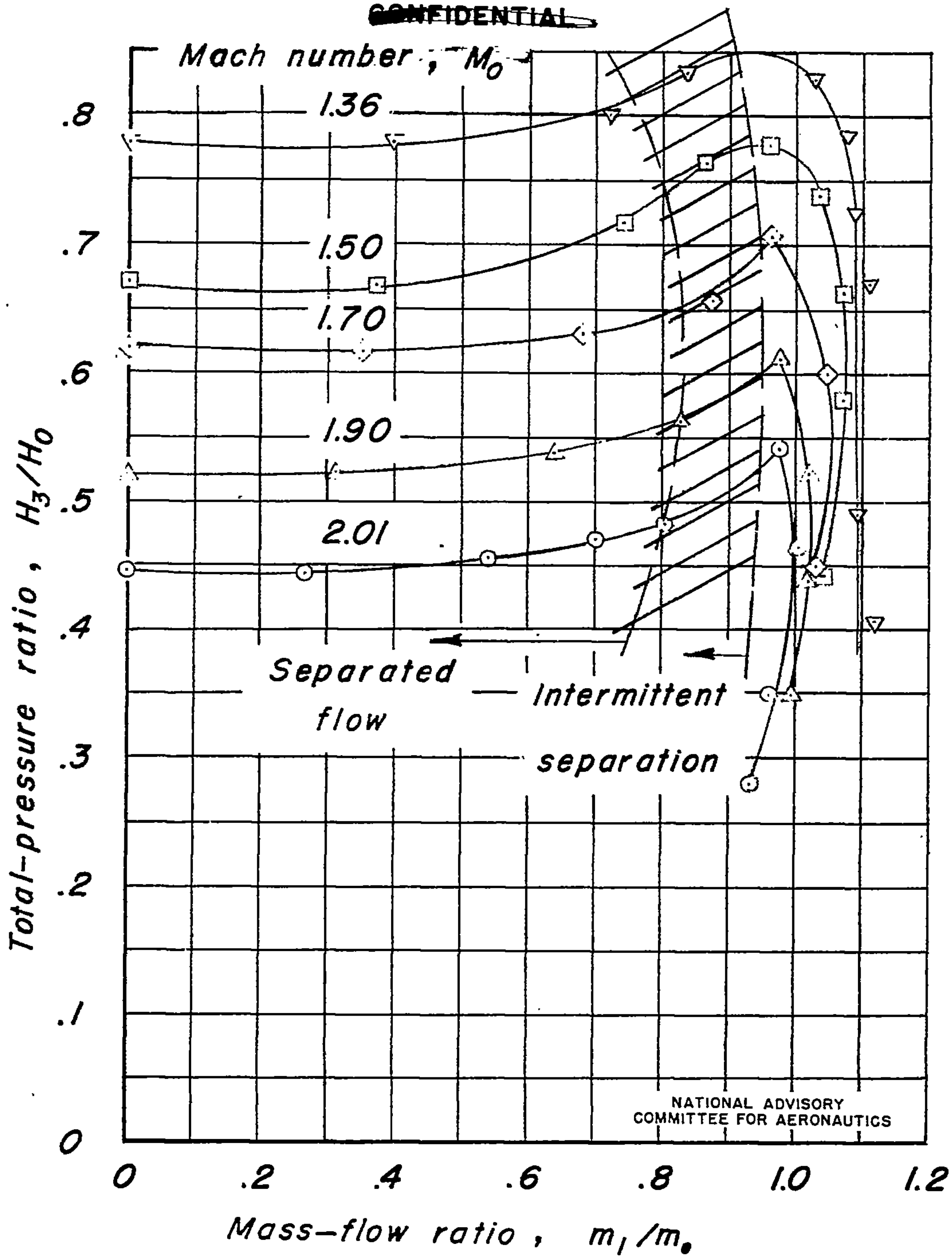

Figure 6.—Variation of total-pressure ratio with mass-flow ratio for the twin-scoop inlet with a 5° ramp.

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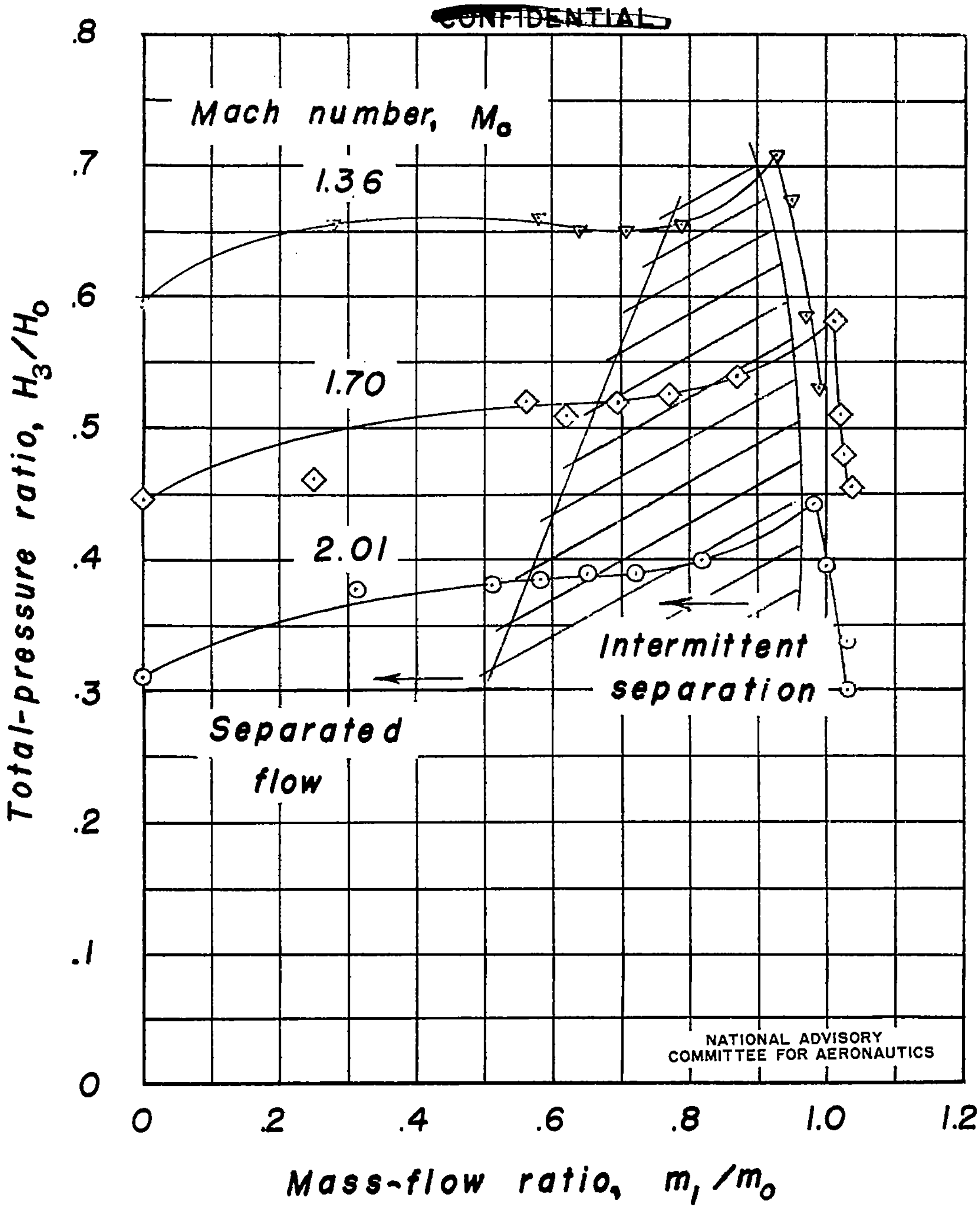

Figure 7.-Variation of total-pressure ratio with mass-flow ratio for the annular inlet with a 5° ramp.

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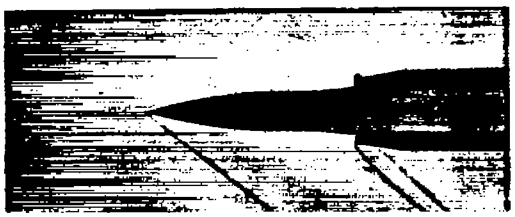
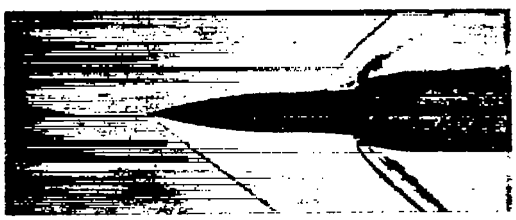
[redacted]

A_4/A_1=1.4 m_1/m_0=1.05 H_3/H_0=0.60

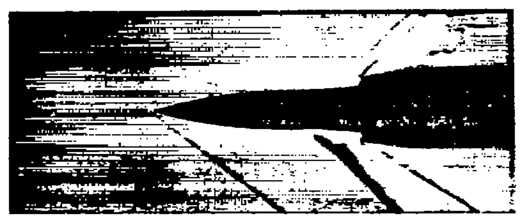


A_4/A_1=1.1 m_1/m_0=0.95 H_3/H_0=0.70

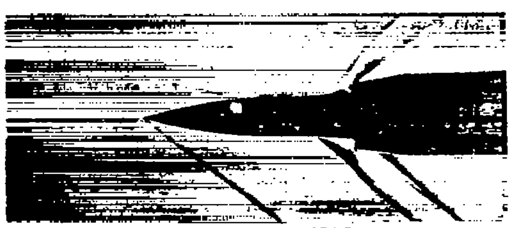
A_4/A_1=1.1 m_1/m_0=0.95 H_3/H_0=0.70



A_4/A_1=1.0 m_1/m_0=0.87 H_3/H_0=0.66



A_4/A_1=1.0 m_1/m_0=0.87 H_3/H_0=0.66



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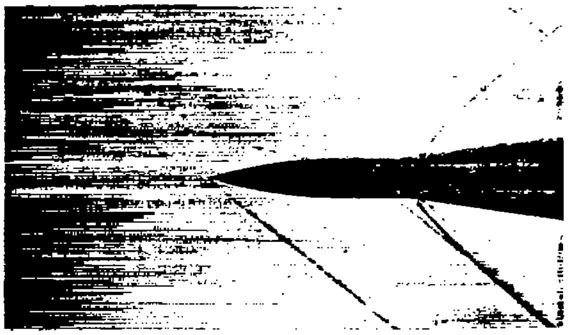
A_4/A_1=0.8 m_1/m_0=0.68 H_3/H_0=0.63

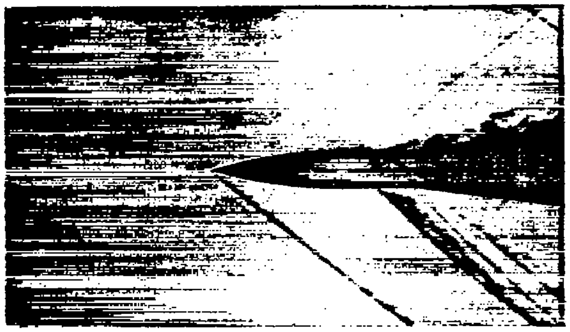
Note: Knife edge parallel to the stream direction.

Figure 8.— Schlieren photographs of the flow ahead of the twin-scoop inlet at a Mach number of 1.70 at various outlet-inlet area ratios.

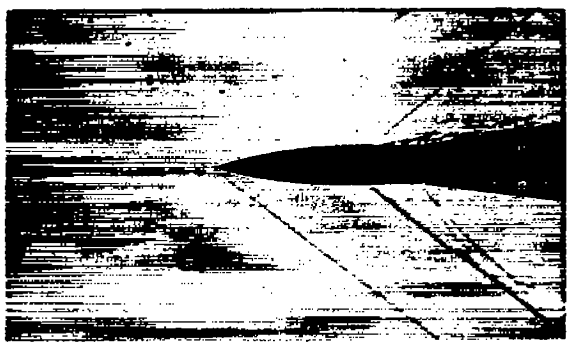
[redacted]



$A_4/A_1=1.4$ $m_1/m_0=1.05$



$A_4/A_1=1.0$ $m_1/m_0=0.87$



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$A_4/A_1=0.8$ $m_1/m_0=0.68$

Note: Knife edge parallel to the stream direction.

Figure 9.- Schlieren photographs of the flow along the sides of the twin-scoop inlet at a Mach number of 1.70 at various outlet-inlet area ratios.